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Subject: SEMI-ANNUAL STATUS REPORT ON NASA GRANT NSG 456: AN INVESTIGATION OF GRAVITY LEVEL PREFERENCE AND THE EFFECTS OF GRAVITATIONAL FORCES ON SMALL ANIMALS AND PRIMATES, AND OF TECHNIQUES FOR RELATED SPACE FLIGHT EXPERIMENTS.

This report is a follow-up to the status report of 22 December 1964.

PUBLICATIONS

In addition to the previously mentioned paper K. O. Lange, R. E. Belleville and F. C. Clark: "Ueber das Verhalten kleiner Tiere unter raumfahrtbedingten Beschleunigungen" the following presentations of results of this research project were made during the reporting period:

R. C. Martin & W. K. Richardson: "Hyper-gravity as an aversive stimulus", 1965 Meeting, Southeastern Psychological Association.

K. O. Lange & A. B. Broderson: "Animal behavior in fields of simulated gravity", 1965 Annual Meeting, Institute of Environmental Sciences (published in the "1965 Proceedings" of the Institute of Environmental Sciences.)

K. O. Lange, R. C. Martin, A. B. Broderson and W. K. Richardson: "Acute & Chronic Centrifugation of Rodents", 1965 Autumn Meeting, The American Physiological Society.

Individual papers on the various phases of experimental

research with rodents and birds in parabolic and spiral centrifuges are in preparation.

The NASA office of Behavioral Biology (Space Sciences) has been informed by personal contacts and occasional memos of progress made during the reporting period.

RESEARCH PERSONNEL

The entire project is directed by the undersigned with Dr. Fogle C. Clark as chief consultant. It falls into the following distinct phases:

1. Determination of gravity level preference in gravity fields of one g up (Dr. Martin and staff)

2. Development of techniques for gravity preference measurements over the range of weightlessness to earth's gravity in space probes (A. B. Broderson and staff)

3. Determination of the responses of restrained primates to simulated gravities programmed on the 12' centrifuge with variable angular speed (Dr. Martin, T. D. Sharp and staff)

4. Design and construction of the 50' centrifuge facility with simultaneously variable angular speed and radius (T. D. Sharp, Dr. Carter and staff), and preparation of the computer programs for its operation (D. Johnson)

5. Chronic centrifugation (guest investigators and staff)

6. Preliminary work toward the application of these gravity research methods and techniques to studies of the response of organisms to mechanical vibrations (Drs. Funk and Martin)

GRAVITY LEVEL PREFERENCE IN FIELDS OF ONE g TO TWO g

The gravity fields consist of parabolic and spiral centrifuges as previously described.

During the reporting period parabola P4 was constructed, and all test programs with rats anticipated for it, were carried out. The apparatus is now in the process of being modified into version P5 to be used principally with squirrel monkeys.

The above tests consisted of original and repeat exposures of significant numbers of rats to the range of 1g to 2g in the parabolic centrifuges and the measurement of time spent at the various gravities. Equivalent measurements were also carried out

on the spiral centrifuges and these latter experiments moreover included test series over the range of from 1g to only 1.3g.

Test results have been analyzed and are being prepared for publication. They may be summed up, here, in the statement that rats show a pronounced preference for one g, and learn by repeated exposure to the gravity field to show their preference within seconds. There is reason, therefore, to assume that valuable information on the rats' preference over the region from near weightlessness to near earth's gravity, can be obtained through relatively inexpensive short ballistic flights. Work on the techniques for such flights is described below.

Centrifuge P2 is presently used for the study of the behavior of birds. Chicks have been, and parakeets are being exposed to gravities of 1g to about 3g. It is expected that birds might react differently to the rotational effects which accompany the production of simulated gravities by centrifugation. These experiments have not yet been concluded.

Experiments for a conditioned-suppression study have been terminated. The data analysis shows that this study should be taken up again - at a later time - with more elaborate equipment.

Attempts to produce and raise rats on the "breeder centrifuges" at 2.6g have not been as successful as the prior efforts with mice, however, the work is being continued with modifications in the procedures. A number of rats are on hand having been exposed to 2.6g continuously from ten days after birth.

GRAVITY LEVEL PREFERENCE BETWEEN ZERO AND ONE g

An ultimate goal of this investigation is to give animals an opportunity to choose any desired gravity between earth's gravity and weightlessness over periods of time of the order of months. This ought to establish clues on how much gravity should be provided in manned space vehicles during long flights. Such animal experiments require orbital flights. They are complicated, time consuming and expensive. It is thought, that short (5 to 10 minutes) free fall trajectories will provide the means of, firstly, providing some of the answers and, secondly, affording the opportunity of testing methods and techniques off the earth's surface. Space probes with rockets similar to the Aerobee 150 are under consideration.

The prospective space apparatus is logically based on laboratory prototypes with which considerable operating experience exists by now. The principal difference lies in the fact that only centrifugal acceleration ensues in the coasting flight above the atmosphere while the vector additionsof earth's g and centrifugal acceleration

act in the laboratory. Moreover, the space apparatus must be or must contain a life support system. There must be provision for collapsing the apparatus into a nose cone or for using the nose cone itself and the subjects must be protected against the stresses of the powered portion of the flight. Recovery does not seem to be vital, but it appears to be essential that the apparatus can also be operated in the laboratory on earth, so that flight simulation may be carried out for the training of the animal subjects as well as that of the human operators.

A number of versions are under considerations: an inflatable cone to simulate paraboloid P2, a V shaped centrifuge to simulate the parabolas, an inflatable spiral, and a rotating capsule-counterweight centrifuge, having the characteristics of centrifuge C1 on the basis of constant angular momentum. The V shaped centrifuge appears to be most feasable at the moment.

The subject's position in the gravity field must be monitored and telemetered. Measuring the radiation intensity of radioactive material attached to the animal is feasable, however, no standard detector is readily available for space use and the disposition of the radioactive substance presents somewhat of a problem. Replacing the photographic methods, which have proved satisfactory in the laboratory, by televised observation is possible but appears more cumbersome than necessary. Weight operated platforms will, of course, not work in the state of weightlessness. Photoelectric methods are applicable. In the process of improving on presently used photoelectric arrangements, a new technique was developed which has all the earmarks of being superior. Transistor circuits react to the electrical conductance of the animal along a runway which consists of individual metal rods spaced approximately 1/2 inch apart. These bars are swept by a ring counter thereby establishing the location of the subject periodically. This intelligence may be telemetered by a one channel transmission. Further development is still required because, surprisingly, test rats reacted to the presently used 24 Volt DC potentials.

Consultation with NASA engineers and rocket manufacturers on the feasibility and practicability of present designs is in progress, and an improved version of the novel detection method is being installed in centrifuge P5 for operational testing.

THE EFFECTS OF GRAVITATIONAL AND ROTATIONAL FORCES ON PRIMATES

The ramifications of the interaction of centrifugally simulated gravities and simultaneously produced motion sickness factors have been pointed out in previous proposals and reports pertaining to this grant. When the subject is allowed to roam a rotating gravity field at will, it and not the researcher, controls

the ensuing Coriolis accelerations. In contrast to the parabolic & spiral centrifuges Centrifuges C1 and C2 are designed to restrain the animal and to let the operator program gravity, rate of change of gravity, manner of change and thereby tangential acceleration.

Construction of Centrifuge Facility C1 was finished during the reporting period, and operations with squirrel monkeys have been taken up and continued almost without interruption.

This centrifuge is some 12 foot in diameter and rotated by a variable speed motor. An animal capsule is pivoted (at present at one fixed radius) on one arm and is subjected (at present) to gravity accelerations of from 1g to 2g. The squirrel monkey is restrained in a chair inside the capsule. There is provision for food and water. The instrument panel has (at present) one retractable lever and a cue light. A television camera on the capsule and its monitor at the operators console permit close observation of the subject. A novel communication system between the centrifuge and its outside complex of psychological instrumentation and centrifuge controls, furnishes an ample number of channels with a minimum number of sliprings.

Since only the rate of rotation but not the radius of Centrifuge C1 can be programmed, any variation of the g-level of the capsule is accompanied by a corresponding tangential acceleration. Complete ignorance existed on which one of these two factors would have a more pronounced effect on the subject's behavior. The first experiments, therefore, had to be designed to create some clarification in this respect. In a conference among Drs. Belleville, Clark, Martin and the undersigned it was decided to disregard for the time being previously made proposals and to start the experiments with a new schedule suggested by Belleville. The execution is as follows:

A naive monkey is acquainted with the restraint chair through a number of short sessions outside the capsule. For a test he is put into the capsule and the centrifuge is brought to very slow rotation, enough to overcome the discontinuity between complete quiet and operation, but not enough to cause gravity to increase appreciably above one g. A Data Trac then takes over further control of the centrifuge. It holds gravity at nominal one g for 15 minutes. The rate of rotation is then increased as a function of time so that simulated gravity is linearly increased from one g to two g in three minutes. When two g is reached, the retractable lever comes out and a cue light comes on. The capsule remains at two g until the subject pushes the lever. Immediately upon this action the centrifuge returns to nominal one g at the linear rate of one g per minute, while the lever retracts and the cue light goes out. After 15 minutes at one g the procedure repeats itself. A test is terminated for the day after seven such trials.

This procedure turned out to be immediately successful in that the two subjects used so far demonstrated aversion to the two g level by learning within a few days to push the lever regularly within seconds.

The above procedures have since been supplemented by additional schedules, but as the research is still in progress further comment on the results would be premature.

DESIGN AND CONSTRUCTION OF CENTRIFUGE C2

Centrifugally simulated gravity is a function of angular speed ω and radius r of centrifuge and capsule. One and the same gravity level may be obtained either by slow rotation on a long arm, or, by fast rotation on a short arm, and the same gravity may be maintained while properly varying ω and r. Similarly, any rate of change of g may be controlled either by variation of ω, or, by variation of r, or, by proper simultaneous variations of both ω and r. Variation of ω produces a tangential acceleration, the effects of which superimpose on the pure gravity effects. Variation of r also produces a tangential acceleration, namely the Coriolis acceleration. However, when ω and r are simultaneously varied such that the angular momentum ramains constant, then g can be varied without tangential side effects. Centrifuge C2 has been designed to be operated at any of the above conditions for the purpose of separating behavioral responses caused by "simulated gravity" from those caused by "rotational environment."

In order to obtain optimum test ranges, it is obviously desirable to be able to vary r and ω from very small to very large values, at meticulously controlled rates. For practical reasons (available funds) a choice was made for a maximum diameter of 50 feet, a payload of 100 lb, a maximum gravity acceleration of only 2g, but considerable magnitudes of angular accelerations and radial velocities.

Both the ω and r drive motors are electrohydraulic. Various commercial versions have been investigated and a definite order is about to be placed. A novel r drive mechanism has been devised and is under construction in the University of Kentucky machine shop. The magnesium super structure has been designed and will be built in house or ordered, depending on final cost estimates. Capsules and the communications system are simular to the ones proven successful on Centrifuge C1 and are also being built in house. The centrifuge will be controlled by an IBM 1800 process controller, to be delivered in April 1966, and two engineering assistants are now undergoing intensive training in programming this equipment.

There is at present no space in the Wenner-Gren Aeronautical Research Laboratory building for a centrifuge of this size, but, the undersigned is happy to report that the Commonwealth of Kentucky

has appropriated funds for a new building to be specifically constructed to house Centrifuge C1, and to be located adjacent to the present Laboratory. A State appointed architectural firm is presently working on plans for this building in cooperation with the Laboratory's engineering staff. It is planned to start assembly of the centrifuge irrespective of the time schedules of the building construction.

CHRONIC CENTRIFUGATION

Test subjects are exposed to the extraterrestrial gravity of 2.6g over long periods of time on the "breeder centrifuges" in order to be tested afterwards in the gravity fields. The "breeder centrifuges" were originally designed for mice and are not really satisfactory for rats. For this reason, and also for physiological studies of subjects exposed to various fixed gravities over various fixed periods of time, another 12' centrifuge in the shape of a triple toroid was designed, constructed and put into operation. For a NASA supported study of the effects of centrifugally generated gravities on braincells (Dr. Robert Grennell) some fifty rats were subjected on this centrifuge to 1.5g, 2.5g and 3.5g for a month, a week and two days. Brain slices were prepared from these subjects by personnel of the University of Maryland at the Wenner-Gren Aeronautical Research Laboratory, and taken to Baltimore.

A study of bone development on guinea pigs was then started by Dr. Zechman of the Department of Physiology and Biophysics of the University of Kentucky and Dr. Thornton of the Lexington Veterans Hospital. These animals refused to eat on the centrifuge and when mortality reached a critical point the study had to be discontinued for the time being.

PRELIMINARY VIBRATIONS RESEARCH

The Wenner-Gren Aeronautical Research Laboratory is engaged in research on the response of the human body to mechanical vibrations under contract with the U. S. Air Force. At the present time a series of species of animals are subjected to intense simusoidal vertical vibration on the University of Kentucky Shake Facility in order to determine the dynamic characteristics of their bodies. These animals substitute for human test subjects because of the danger of injury inherent in the test procedures. Since the animals must be anesthetized, their dynamic response is passive and does not furnish the exact parameters, which would be obtained if the subjects were able to counteract the imposed stresses by voluntary or involuntary reflex action.

It appeared to the undersigned that the methods of experimental psychology, used in this gravity study, would lend themselves well

to an investigation of the effects of vibration on organisms fully capable of adjusting themselves to the imposed stress. In discussing this with Dr. Belleville the following approach evolved: An animal subject is exposed at any one of a series of frequencies to a given vibration amplitude. The animal is trained to gradually reduce this amplitude (and thereby the velocity and acceleration of vibration) by pushing a lever. Simultaneously, however, it receives gradually increasing electric shock, so that it is forced to trade shock intensity for vibration intensity. The shock intensity is easily measured and would convey a numerical value for the aversity of the degree of vibration at any frequency of the frequency range. Correlation with the results obtained on anesthetized subjects should make explicit the extent to which the subject is able to adjust its physical parameters to suit the imposed stress.

The idea is being pursued by Dr. Martin of the Wenner-Gren Aeronautical Research Laboratory and Department of Psychology and Dr. Funk of the Department of Mechanical Engineering of the University of Kentucky. An animal compartment and restraint chair suitable for vibration tests have been designed and constructed. A shocker has been devised, the potential of which may be altered in variable steps, and training of a squirrel monkey has commenced. Testing of the principle of the proposed procedure will be undertaken on the present shaketable, but it is expected that a complete study will require a shaker specifically instrumented for such tests.

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